Distributed Algorithms for Maximizing the Lifetime of WSNs with Heterogeneity for Adjustable Sensing Ranges

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Abstract

In this paper, we study the impact of heterogeneity on homogeneous protocols. Most of the protocols for increasing the lifetime of wireless sensor networks are designed for homogeneous networks. The load balancing protocol with adjustable sensing range (ALBPS) and deterministic energy efficient protocol with adjustable sensing range (ADEEPS), are two important homogeneous protocols. In this work, we incorporate 3-level heterogeneity to the ALBPS and ADEEPS and the resultant protocols are named as heterogeneous load balancing protocol with adjustable sensing range (HALBPS) and heterogeneous deterministic energy efficient protocol with adjustable sensing range (HADEEPS), respectively. We compare the performance of the ALBPS and ADEEPS protocols with that of the HALBPS and HADEEPS protocols. The simulation results indicate that the heterogeneous protocols further prolong the network lifetime.

Keywords

Heterogeneity; Energy-efficiecy; Targets; Sensing Range; Wireless Sensor Networks

Introduction

The wireless sensor networks (WSNs) establish a basis for a wide range of applications related to security, monitoring, disaster relief, surveillance, military, health care and environmental applications [1]. In the WSNs, the sensor nodes collect information from the monitoring area and transmit that information to the active sensor nodes. The active sensor nodes perform aggregation and send the resultant information to the sink for further processing [2]. A lot of research in WSNs has been done and is still being done on the energy efficiency problem. The existing research suggest that the energy saving mechanism can be implemented either adjusting the transmission or sensing range or scheduling the sensor nodes to alternate between active and sleep mode [1, 3-5] or their combination. Another solution for energy efficiency is node heterogeneity. In this paper, we discuss ALBPS and ADEEPS by incorporating three types of heterogeneous nodes. We consider a sensor network in which the sensor nodes and targets are deployed uniformly over the monitoring region and their positions are known. The sensor nodes have different amount of energies, which are generally called as heterogeneous sensor nodes. A heterogeneous network consists of three types of nodes depending on their energy levels and we may name them as normal, advance, and super nodes [6-8]. The super nodes are equipped with more energy than the advanced nodes that in turn have more energy than the normal nodes. We consider three aspects in reference to improving the lifetime of a WSN that includes scheduling algorithms, adjusting sensing range, and heterogeneity of sensors. In [9], the load balancing approach for increasing the network lifetime is discussed. The algorithms in [9] solve the target coverage problem by scheduling and fixed sensing range approaches, which may be considered as an extension of the work discussed in [5] in which a sensor can participate in multiple cover sets unlike in [9]. In [10], it is shown that non-disjoint sensor covers provide better lifetime as compared to the disjoint set covers. The works in [1,4,11] discuss adjustable sensing range approach for increasing the lifetime. Dhawan et al. used both scheduling and adjusting sensing ranges and proposed two localized and distributed scheduling algorithms: ALBPS and ADEEPS with adjustable sensing range for coverage problem [12]. In this paper, we use network heterogeneity model for prolonging the network lifetime by considering three types of sensor nodes: normal, advance, and super nodes. We incorporate the heterogeneous network model in ADEEPS and ALBPS algorithms and call them as heterogeneous load balancing protocol with adjustable sensing range

(HALBPS) and heterogeneous deterministic energy efficient protocol with adjustable sensing range (HADEEPS), respectively. The rest of the paper is organized as follows. Section 2 discusses the propose network model. In Section 3, the distributed algorithm of the proposed model is given. The results and simulation are discussed in section 4. Section 5 concludes the work.

Proposed Sensor Network Model

The network model considered here is similar to the models discussed in [1, 3, 5, 9, 11]. The sensor nodes are deployed over the monitoring region. Each sensor knows its ID, battery, and coordinates of all the covered targets and self. A sensor collects information about all targets covered by it without intervention of any other sensor node. In our proposed network simulation model, a sensor is either in the communication mode or monitoring mode. The active nodes, which are initially the super nodes, cover the targets. If the super nodes are unable to cover all targets, then some of the advance nodes become active nodes that can cover the targets. If some of the targets are still not covered, then some of the normal nodes that can cover the remaining targets become active. Assuming that all active nodes are super nodes, then during the reshuffle time the energy level of the active nodes becomes less than that of the advance nodes (non-active nodes) that can cover all targets. The active nodes are replaced by the advance nodes. If advance nodes were the active nodes, then during reshuffle time they are replaced by normal nodes (non-active nodes) that can cover all targets. The duration of one set of active nodes constitutes a round. During a round one set of nodes remains active and in next round some other set of nodes become active. This process continues until all nodes have become active. This process constitutes an epoch. In next epoch, same process continues. When some of the nodes become dead and do not allow any communication, the network is said to be dead.

Proposed Algorithms

In this section we will discuss two distributed algorithms HALBPS and HADEEPS algorithms. In these algorithms, a sensor at any given point of time can be in one of the three states.

- Active state: the sensor is active and monitors the targets.
- Idle state: in this state, the sensor listens to other sensors, but does not monitor targets.
- Deciding state: in this state, the sensor monitors targets, but will alter its state to either active or idle state soon.

These algorithms are designed to characterize the adjustable sensing range. Their distinct characteristics are discussed in 3.1 and 3.2, respectively.

Heterogeneous Load Balancing Protocol for Adjustable Range Sensing (HALBPS)

The HALBPS protocol is characterized by adjustable sensing range and sensor node heterogeneity. At the beginning each sensor disseminates its battery level to cover the targets and then stays in the deciding state with its maximum sensing range for finding sensors cover schedules. Each sensor will change its state by adopting the transition rules as given below. A sensor in the deciding state with range *r* shall change its state into active, deciding, and idle state.

- if there is a target at range *r* which is not covered by any active or deciding sensors (it will go to active state with sensing range *r*).
- if all covered targets at range *r* are covered by either active or deciding sensors with a more prominent monitoring time, then its sensing range will be decreased to the next furthest away target (it will remain in deciding state).
- if a sensor decreases its range to zero (it will go to idle state).

Heterogeneous DEEPS Protocol for Adjustable Range Sensing (HADEEPS)

In this protocol, one of the targets is selected as hill, which is monitored by maximum energy of the nearby sensors and the remaining targets are referred to as sink. Each target has at least one sensor node as its in-charge. Denoting the battery of ith sensor as b_i, r_i as sensing range, and e as energy dissipation model, the maximum lifetime of the network is given by the sum of the lifetime of all sensors, i.e. $Lt(b_1, r_1, e) + Lt(b_2, r_2, e) + Lt(b_3, r_3, e) + \ldots + Lt(b_k, r_k, e)$, where $Lt(b_i, r_i, e)$ signifies the duration for which a particular target is monitored, assuming that the target is monitored by the sensors $s_1, s_2, \ldots, s_k$. Once the hill node is decided, we decide its in-charge node as given below:

If the target is sink, one of the sensors other than the monitoring sensor covering that target which has least energy with respect to the target is the in-charge of that target.

If the target is hill, then one of the sensors other than the monitoring sensor whose energy effect with respect to the hill is maximum is the in-charge of that target.

When a sensor is in the deciding state with range *r*, its state changes into active or idle state as follows:

- if there is any farthest target at range less than or equal to *r* that is not covered by any active or deciding sensor, the sensor goes into active state with sensing range *r.*
- whenever a sensor is not in-charge of any target except those already covered by the active sensors, it goes to idle state.

For both the algorithms, the decision of all the states is decided by the sensors and each sensor will stay in that state for a specified period of time, called shuffle time, or up to that time when the active sensor consumes its energy and becomes dead. A network will fail if there is a target which is not covered by any active sensor.

Modeling and Simulation

The simulator is designed for wide range of physical sensor network sizes with varying node densities. The sensor nodes and targets are placed randomly according to the uniform distribution. For the simulation purpose, a static network of sensors in a 100mx100m area with the adjustable parameters given in Table 1 is designed.

TABLE 1 SIMULATION PARAMETERS

Parameters	Symbols	Values
Number of Sensor Nodes	S	40 ~ 200
Number of Targets	T	25 and 50
The Initial Energy of Each Sensor Node	Ei	2J
Adjustable Sensing Ranges	P (r_1, r_2)	30m and 60m

It is assumed that the sensor nodes have different initial energies. Let m be the fraction of the total number of nodes n, and m_o be the percentage of nodes m which are equipped with β times more energy than the normal nodes. We call these nodes as super nodes. The rest $n*m*(1-m_0)$ nodes are equipped with α times more energy than the normal nodes; we refer to these nodes as advanced nodes and the remaining $n*(1-m)$ as normal nodes. Let E_0 be the initial energy of a normal node. The energies of a super node and advanced node are given by $E_0(1+\beta)$ and $E_0(1+\alpha)$, respectively. We have used to energy dissipation models: linear and quadratic as defined in [13]. The linear energy model is defined as $e_p=c_1*r_p$, where the energy e_p is needed to cover a target at distance r_p, c_1 is constant; and the quadratic model is defined as $e_p=c_1*r_p^2$, where c_2 is a constant. In order to make comparison, we have used the same simulations parameters as in [1]. The total energy of the heterogeneous network is given by $E = n*E_0*(1+m*(\alpha+m_0+\beta))$. More details can be seen in [12-14]. Both HALBP and HADEEPS algorithms are further modified by using the adjustable sensing range and distribution of heterogeneous sensor nodes. For each algorithm, the following steps have been performed for the simulation:

Step:1. Generate the target and sensor files which contain the information of the target id, target position, sensor id, sensor initial battery, and sensors position.

Step:2. Simulation begins from the command prompt with inputs that include the target and sensor files, the maximum sensing range, and the energy model.

Step:3. The simulation runs till some target cannot be covered by some sensor.

Step:4. When some target becomes uncovered, the simulations stops and the lifetime of the network is printed out as the result.

Results and Discussions

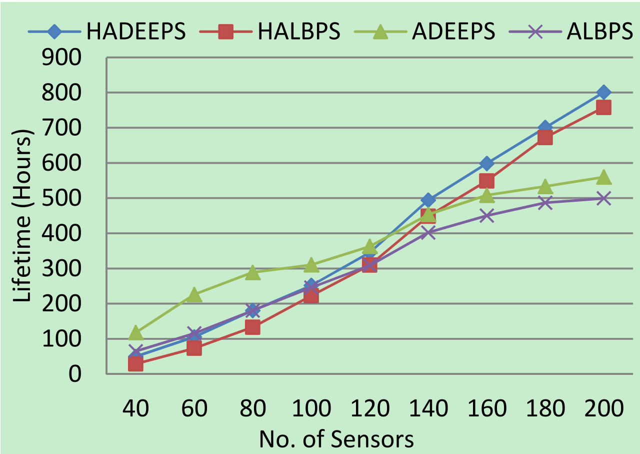
We have compared the network lifetime computed by using ALBPS, HALBPS, ADEEPS and HADEEPS alogirthms by varying the number of sensors. We have also varied the maximum sensing range and the number of targets with various combinations for linear and quadratic energy models.

Case-I: $m=0.2$, $m_0=0.5$, $\alpha=2$, $\beta=1$

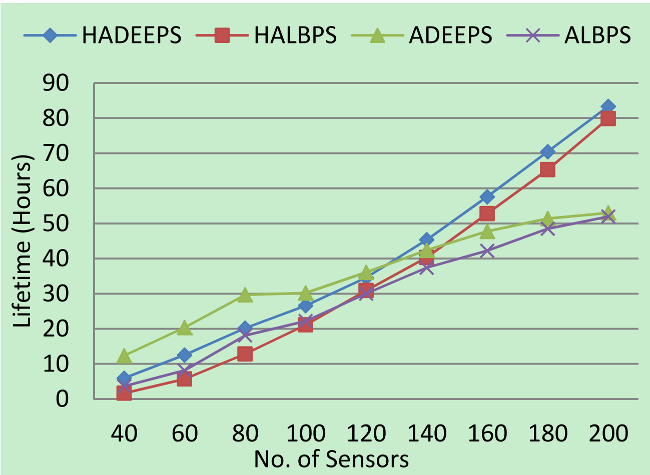
Figs. 2(a) & (b) show the lifetime of the network for linear and quadratic energy models with adjustable sensing range of 30m and 25 numbers of targets.

The results have been obtained for the HADEEPS and HALBPS and compared with ADEEPS and ALBPS. The overall network lifetime significantly improves with HADEEPS and HALBPS in comparison to the existing protocols: ADEEPS and ALBPS for both linear and quadratic energy models. It is evident from the results that for 200 numbers of sensors the lifetimes

obtained are {800, 757, 559, 499} and {83, 79, 52, 51} hours, respectively, for linear and quadratic energy models. In case of linear and quadratic energy models with heterogeneity there is enhancement in lifetime, i.e. {241, 258} and {31, 28} hours of the networks with HADEEPS and HALBPS protocols, respectively.



(a)

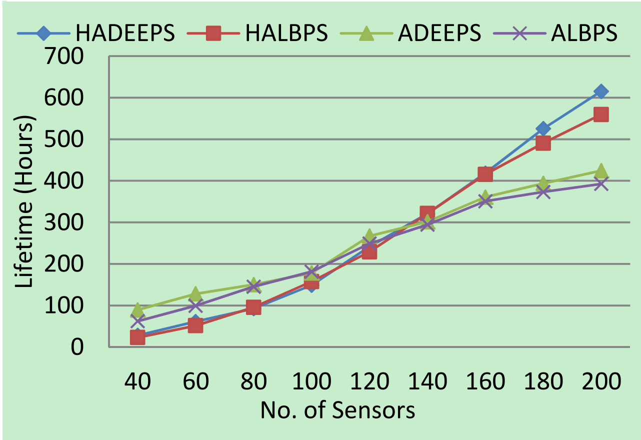


(b)

FIG. 2 LIFETIME FOR SENSOR NETWORKS IN CASE OF (a) LINEAR (b) QUADRATIC ENERGY MODELS.

Figs. 3(a) & (b) show the lifetime of the network in case of linear and quadratic energy models with adjustable sensing range of 30m and 50 targets.

In this case also, the overall network lifetime significantly improves by using HADEEPS and HALBPS in comparison to the existing protocols: ADEEPS and ALBPS in linear and quadratic energy models. For 200 numbers of sensors, the lifetimes are obtained as {615, 559, 424, 392} and {68, 43, 45, 27} hours, respectively, for linear and quadratic energy models. In case of linear and quadratic energy models with heterogeneity there is enhancement of {191, 167} and {23, 16} hours in network lifetime by using the HADEEPS and HALBPS protocols, respectively.



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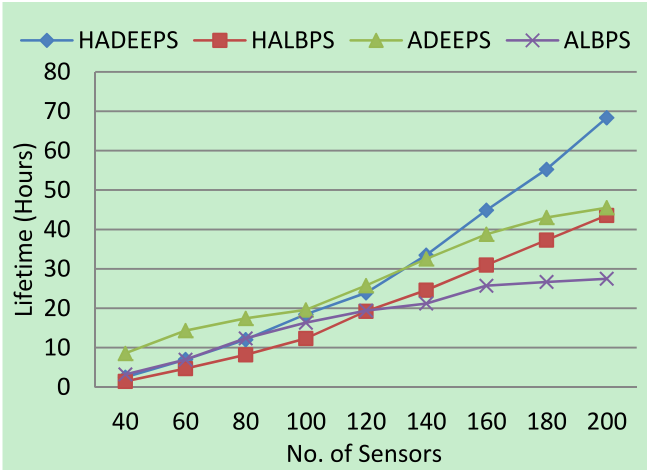
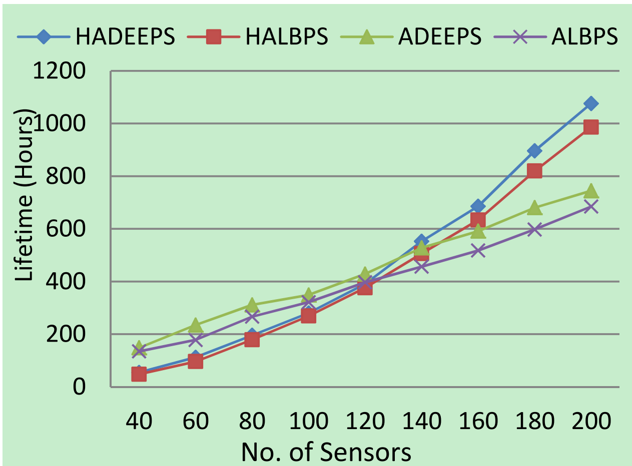


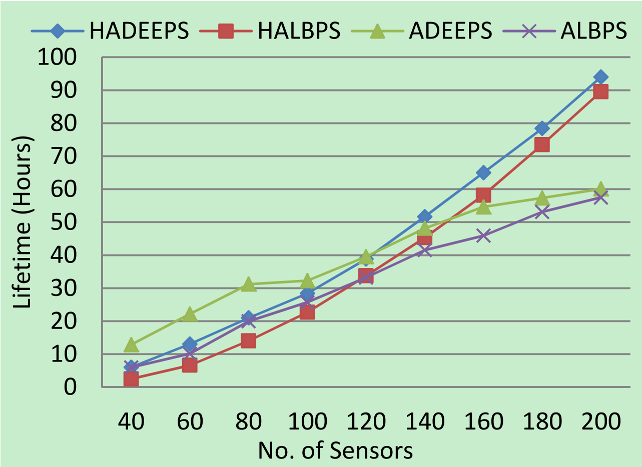
(b)

FIG. 3 LIFETIME FOR SENSOR NETWORKS IN CASE OF (a) LINEAR (b) QUADRATIC ENERGY MODEL

Figs. 4(a) & (b) show that the lifetime of the network in case of linear and quadratic energy models with adjustable sensing range of 60m and 25 targets.



(a)



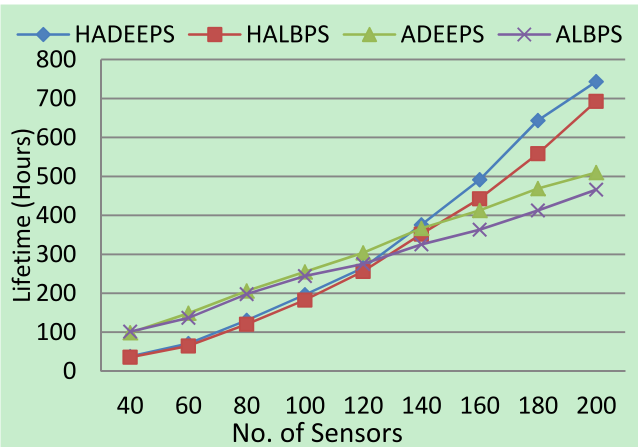
(b)

FIG. 4 LIFETIME FOR SENSOR NETWORKS IN CASE OF (a) LINEAR (b) QUADRATIC ENERGY MODEL

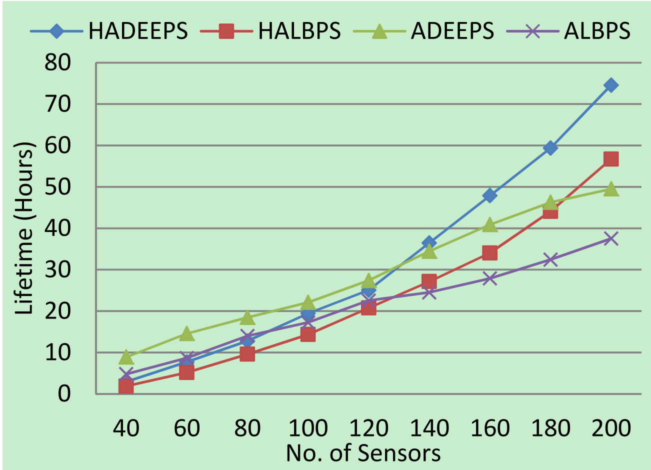
For this case, the overall network lifetime significantly improves by using HADEEPS and HALBPS in comparison to the existing protocols: ADEEPS and ALBPS in linear and quadratic energy models. For 200 numbers of sensors, the network lifetimes are obtained as {1076, 985, 744, 684} and {93, 89, 60, 57} hours, respectively, for linear and quadratic energy models. There is enhancement of {332, 301} and {33, 32} hours in network lifetime by using HADEEPS and HALBPS protocols, respectively, for linear and quadratic energy models.

Figs. 5(a) & (b) show the network lifetime for linear and quadratic energy models with adjustable sensing range of 60m and 50 targets.

The lifetimes are obtained as {743, 692, 509, 465} and {74, 56, 49, 37} hours, respectively, for linear and quadratic energy models. Thus, there is enhancement of {234, 227} and {25, 19} hours in network lifetime for using the HADEEPS and HALBPS protocols, respectively, for linear and quadratic energy models.



(a)



(b)

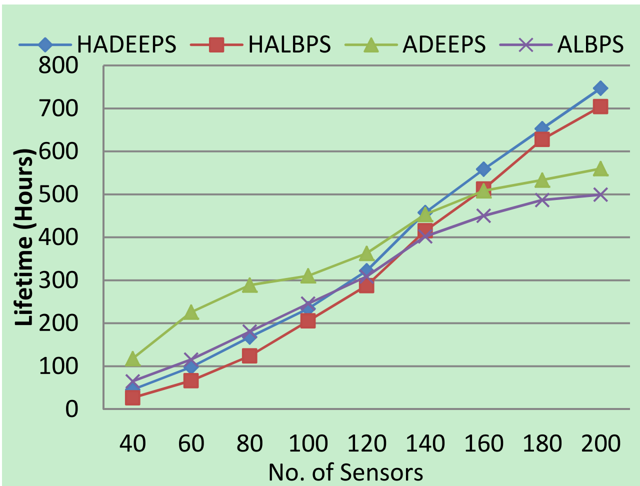
FIG. 5 LIFETIME FOR SENSOR NETWORKS IN CASE OF (a) LINEAR (b) QUADRATIC ENERGY MODEL

Thus, the heterogeneous algorithms have significant impact on lifetime in comparison to homogeneous algorithms.

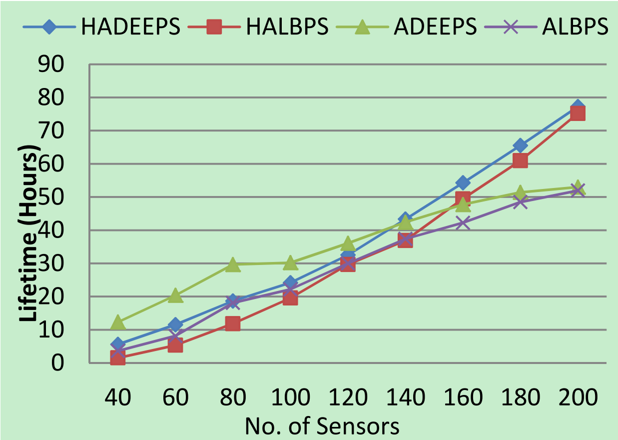
***Case-II:* m=0.2, m_0=0.5, α=1, β=2**

Figs. 6(a) & (b) show the network lifetime for linear and quadratic energy models with adjustable sensing range of 30m and 25 targets.

The results have been obtained for HADEEPS and HALBPS and compared with ADEEPS and ALBPS. The overall network lifetime significantly improves with HADEEPS and HALBPS in comparison to the existing protocols: ADEEPS and ALBPS in linear and quadratic energy models. It is evident from the results that for 200 numbers of sensors the network lifetimes are obtained {747, 704, 559, 499} and {77, 75, 52, 51} hours respectively for linear and quadratic energy models. In case of linear and quadratic energy models with heterogeneity there is enhancement of {188, 205}



(a)

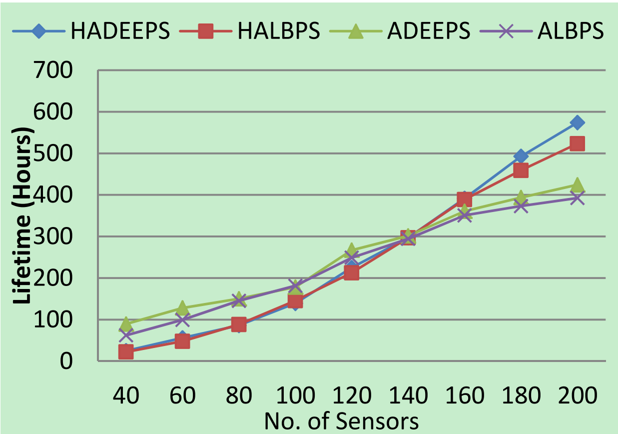


(b)

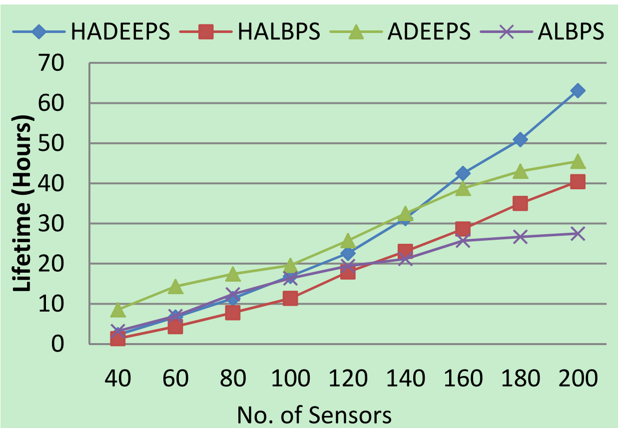
FIG. 6 LIFETIME FOR SENSOR NETWORKS IN CASE OF (a) LINEAR (b) QUADRATIC ENERGY MODEL

and {25, 24} hours in network lifetime of a wireless sensor networks with HADEEPS and HALBPS protocols, respectively.

Figs. 7(a) & (b) suggest the lifetime for sensor nodes in case of linear and quadratic energy model with adjustable sensing range of 30m and 50 targets.



(a)

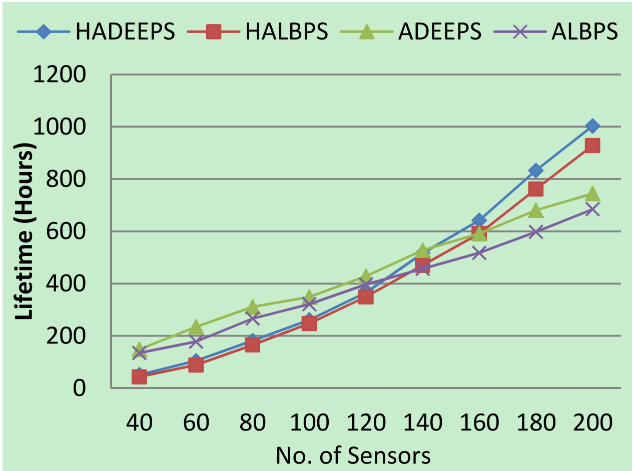


(b)

FIG. 7 LIFETIME FOR SENSOR NETWORKS IN CASE OF (a) LINEAR (b) QUADRATIC ENERGY MODEL

The results have been obtained for HADEEPS and HALBPS and compared with ADEEPS and ALBPS. The overall network lifetime significantly improves with HADEEPS and HALBPS in comparison to the existing protocols: ADEEPS and ALBPS in linear and quadratic energy models. It is evident from the results that for 200 numbers of sensors the network lifetime are obtained {573, 523, 424, 392} and {63, 40, 45, 27} hours respectively for linear and quadratic energy models. In case of linear and quadratic energy model with heterogeneity there is enhancement of {149, 131} and {18, 13} hours in network lifetime with HADEEPS and HALBPS protocols respectively.

Fig. 8(a) & (b) show the lifetime for sensor nodes in case of linear and quadratic energy model with adjustable sensing range of 60m and 25 targets.



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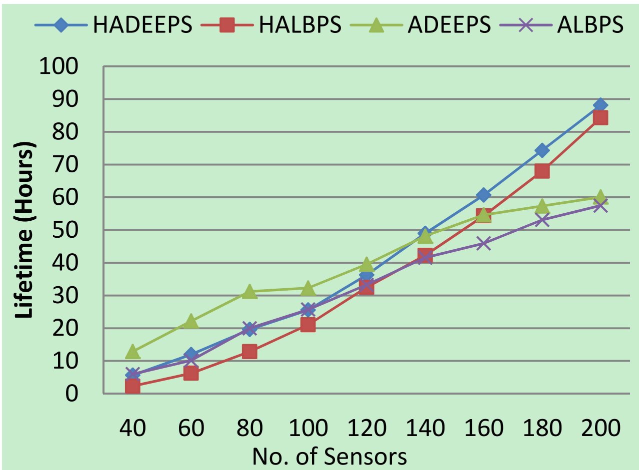


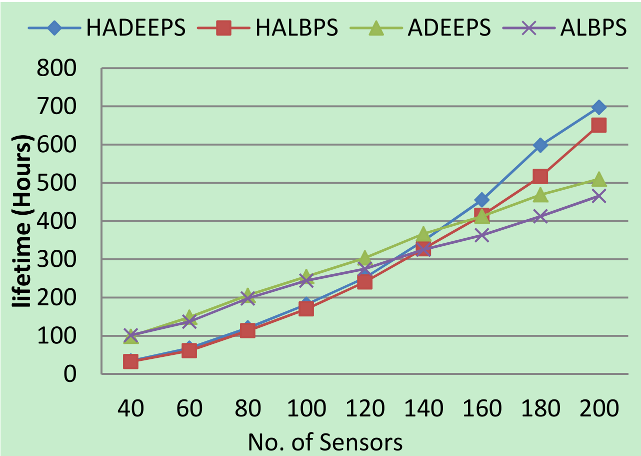
(b)

FIG. 8 LIFETIME FOR SENSOR NETWORKS IN CASE OF (A) LINEAR (B) QUADRATIC ENERGY MODEL

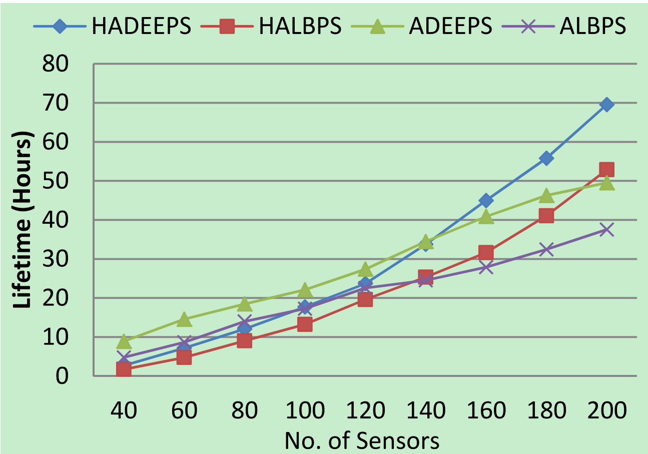
The results have been obtained for modified HADEEPS and HALBPS and compared with ADEEPS and ALBPS. The overall network lifetime significantly

improves with HADEEPS and HALBPS in comparison to the existing protocol ADEEPS and ALBPS in linear and quadratic energy models. It is evident from the results that for 200 numbers of sensors, the network lifetimes are obtained as {1003, 928, 744, 684} and{88, 84, 60, 57} hours respectively for linear and quadratic energy models. In case of linear and quadratic energy model with heterogeneity there is enhancement of {259, 244} and {28, 27} hours in the networks lifetime with HADEEPS and HALBPS protocols respectively.

Figs. 9 (a) & (b) show the lifetime for linear and quadratic energy models with adjustable sensing range of 60m and 50 targets.



(a)



(b)

FIG. 9 LIFETIME FOR SENSOR NETWORKS IN CASE OF (A) LINEAR (B) QUADRATIC ENERGY MODELS

The results have been obtained for modified HADEEPS and HALBPS and compared with ADEEPS and ALBPS. The overall network lifetime significantly improves with HADEEPS and HALBPS in comparison to the existing protocols: ADEEPS and ALBPS in linear and quadratic energy models. It is evident from the results that for 200 numbers of sensors, the network lifetimes are obtained as [697, 650, 509, 465} and {69, 52, 49, 37} hours respectively for linear and quadratic energy models. In case of linear and quadratic energy model with heterogeneity there is enhancement of {188, 185} and {20, 15} hours in network lifetime with HADEEPS and HALBPS protocols respectively.

Conclusions

In this paper, the network lifetime has been improved by incorporating heterogeneity in the sensor nodes. The overall improvement in the network lifetime by using HALBPS over ALBPS is about 42% and that of the HADEEPS over ADEEPS is about 40% for linear energy model. For quadratic energy model, it is even higher. The improvement in lifetime for HALBPS over ALBPS is around 50% and that of the HADEEPS over ADEEPS is about 49%. Thus, the heterogeneous networks have significant impact on lifetime in comparison to homogeneous WSNs.

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